High-redshift Galaxy Bias for Stage-V Spectroscopic Surveys

New Physics from Galaxy Clustering at GGI

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(based on work w/ **Misha Ivanov**, **Carol Cuesta-Lazaro**,
& Ni, Bose, Hadzhiyska, Hernquist, Hernández-Aguayo, Kannan)

arXiv: 2505.03626

The Brinson Foundation

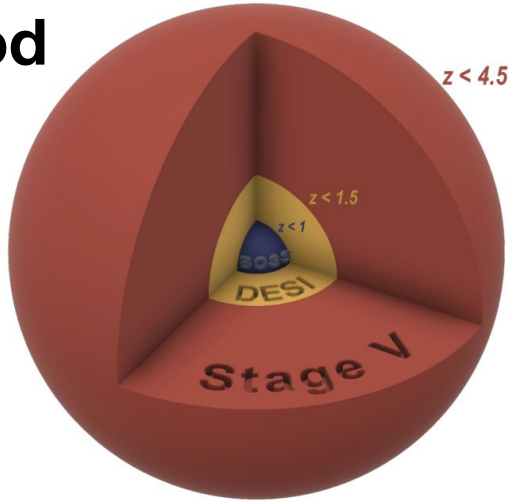
Future surveys

Future of LSS is at $z > 2$ (*Noah's talk*)

DESI-II, Spec-S5 (US), WST (EU), MUST (CN)

↑: large k_{NL}, probe new volume

↓: tyranny of D_L, galaxies not well understood



C. Yeche, Besuner+25, Bacon+24, Zhao+24

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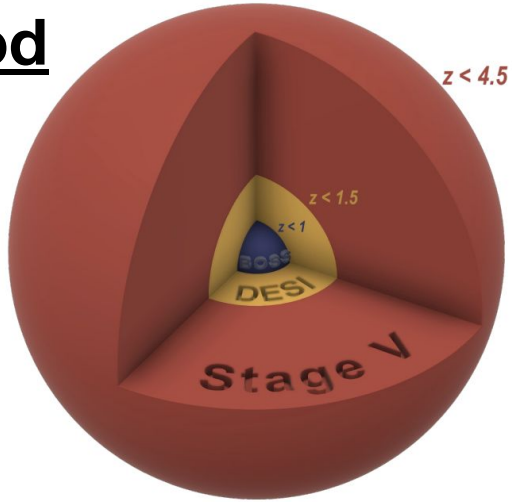


C. Yeche, Besuner+25, Bacon+24, Zhao+24

What kind of galaxies?

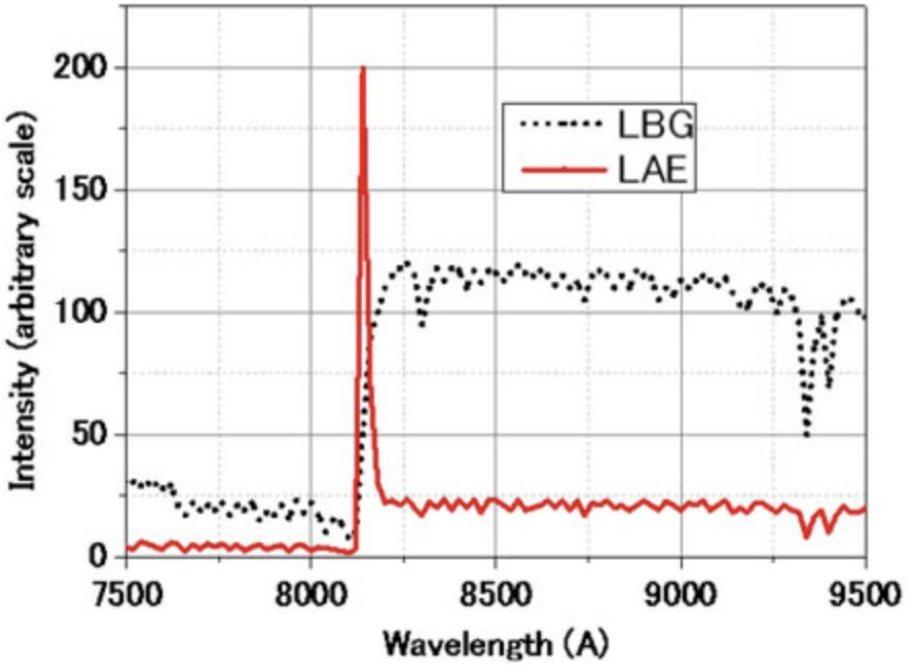
Lyman-alpha emitters (LAEs):

- **Line selection (~ELGs)**
- **Lower mass, bias b_1~ 2**

Lyman-break galaxies (LBGs):

- **Break selection (--)**
- **~Higher mass, brighter, higher bias b_1~ 3.5 - 4**

Both star-forming



Will modeling clustering be hard?

What are higher-order biases? What is k_{max}?

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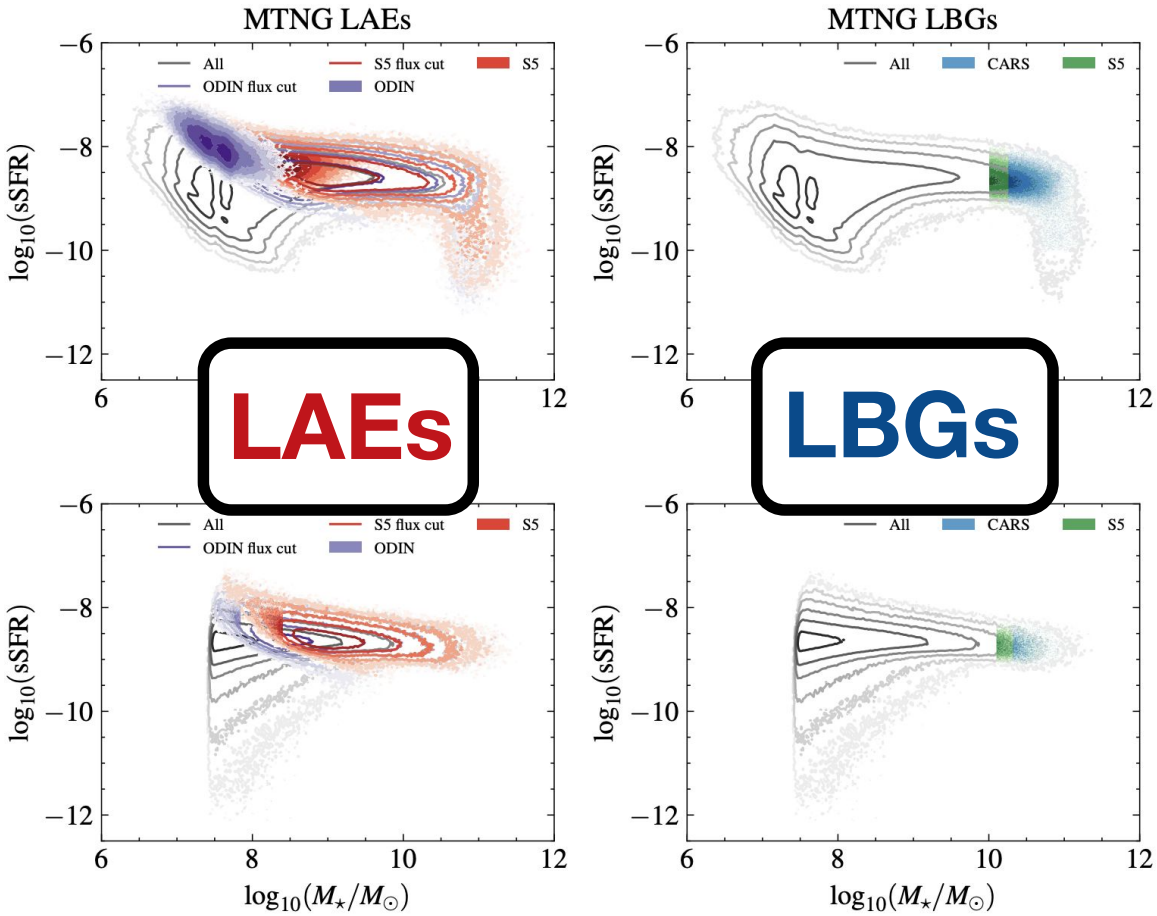
2. **Look at existing (small-field) data (ODIN, CARS)**
3. **Match b_1, number density, to observed $w(\theta)$**
4. **Measure biases, P_{err} at field-level (cancel s.v.)**

Simulation Selection

No realistic colors or spectra

Do best possible w/ hydro properties

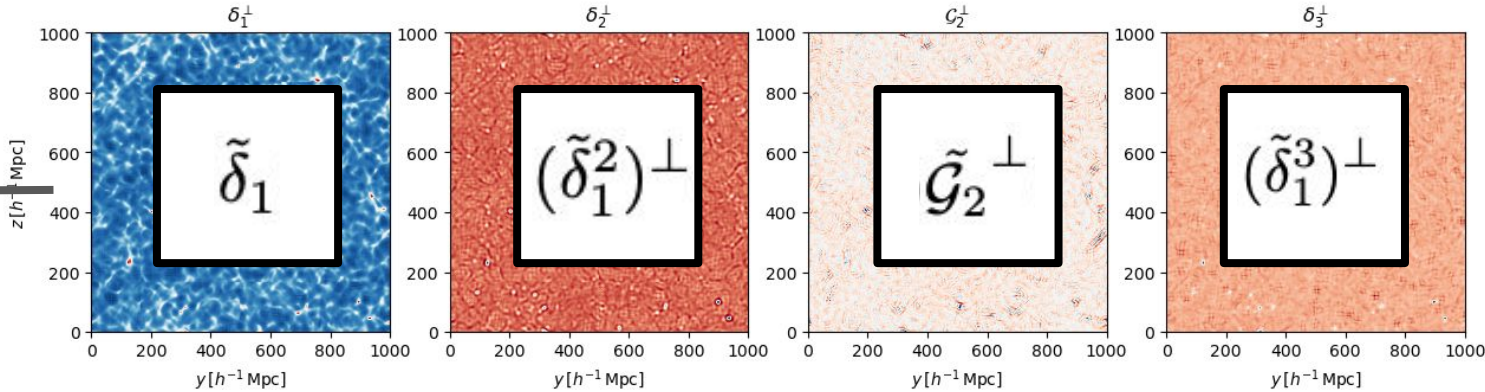
Stellar mass
Star formation rate
Metallicity



Field-level machinery

“Transfer function” tooling *(Misha’s talk, alt. Bea, Fabian’s talks)*

$$\delta^{\rm EFT}(\boldsymbol{k}, \hat{\boldsymbol{z}})$$



Redshift space, look at scale dependence in:

$$P_{\rm err}(k,\mu) = \langle |\delta^{\rm EFT}(\boldsymbol{k}, \hat{\boldsymbol{z}}) - \delta_g^{\rm truth}(\boldsymbol{k}, \hat{\boldsymbol{z}})|^2 \rangle'$$

Schmittful+18,+20, Abidi+Baldauf+16, Ivanov+24a,b,c, JMS+Chen24, Modi+19, Tucci+24, Schmidt25, **Akitsu+25**

Results - k_{max}

LAEs:

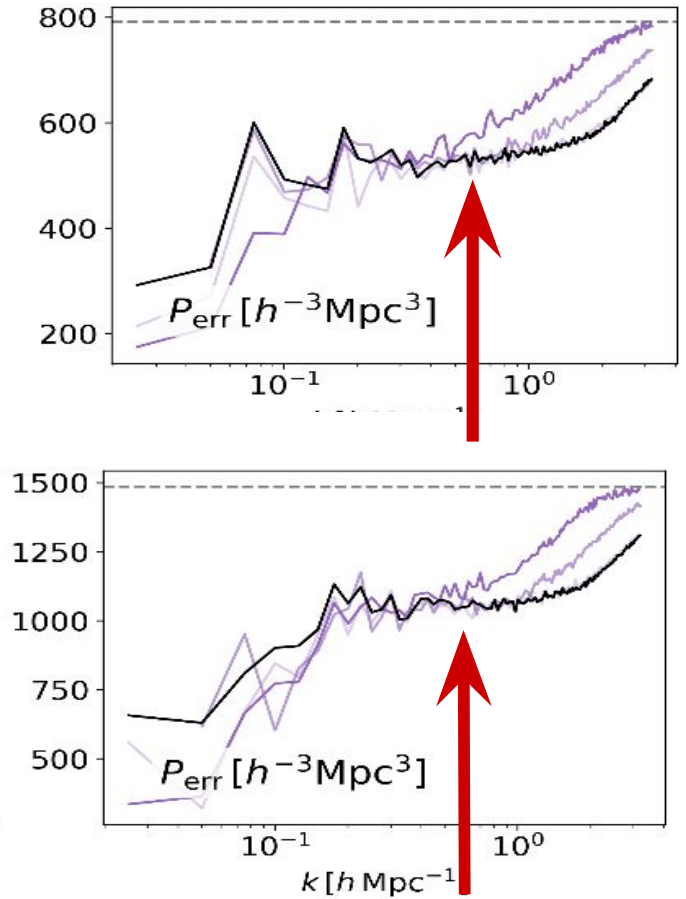
$k_{max} \gtrsim 0.3$ [h/Mpc]

LBGs:

$k_{max} \gtrsim 0.2$ [h/Mpc]

Set by FoG

***Can* be significantly higher**



Conclusions

Take away:

- ***k*-reach of PT similar or better than current surveys**
- **Simulation/selection-dependent**

Now what?:

- **More realistic simulated galaxies** (e.g. ~Khoraminezhad+25)
- **Simulation-based priors**
- **Cheap mock generation**

Extra

EFT model - transfer functions w/ cubic

$$\delta_g^{\rm EFT}(\boldsymbol{k},\hat{\boldsymbol{z}}) = \delta_Z(\boldsymbol{k},\hat{\boldsymbol{z}}) - \frac{3}{7}\mu^2 f\tilde{\mathcal{G}}_2$$
$$\beta_1(k,\mu)\tilde{\delta}_1(\boldsymbol{k},\hat{\boldsymbol{z}}) + \beta_2(k,\mu)(\tilde{\delta}_1^2)^{\perp}(\boldsymbol{k},\hat{\boldsymbol{z}})$$
$$+ \beta_{\mathcal{G}_2}(k,\mu)\tilde{\mathcal{G}}_2{}^{\perp}(\boldsymbol{k},\hat{\boldsymbol{z}}) + \beta_3(k,\mu)(\tilde{\delta}_1^3)^{\perp}(\boldsymbol{k},\hat{\boldsymbol{z}})$$

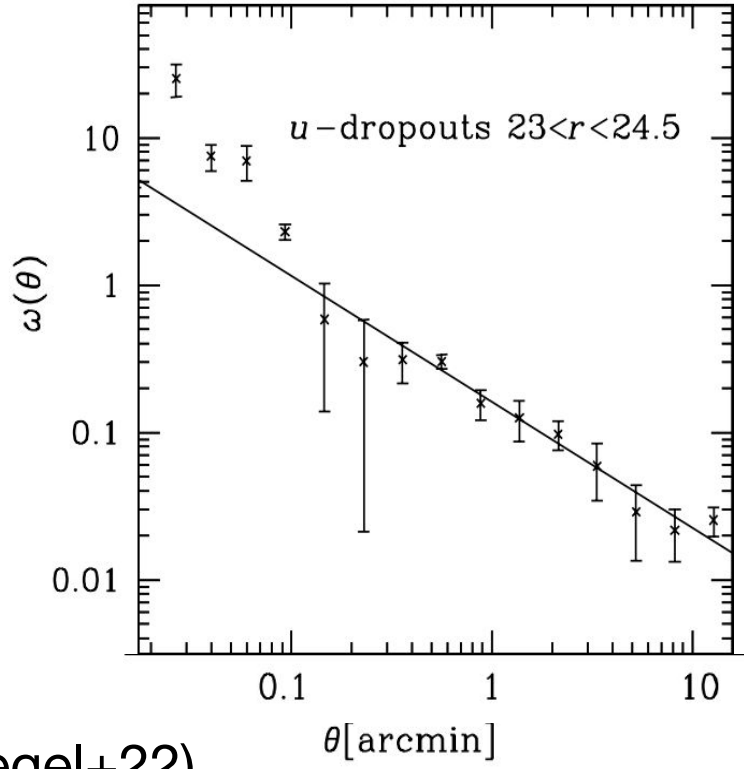
Simulated LBG Selection

Goal - Build a *z*=3 sample that matches:

1. **Comoving number density** $\bar{n}$
2. **Linear bias b_1**

Of two setups:

1. **Existing data - CARS *u*-drop galaxies**
   Hildebrandt+09 ($23 < r < 24.5$, 3 deg^2)
   ~7e-4 [Mpc/h]$^{-3}$, b_1~ 4
2. **Planned data - Spec-S5-like survey**
   Following spectroscopic roadmap (Schlegel+22)



Besuner+24, Hildebrandt+09, Schlegel+22

Simulated Selection

Simple procedure:

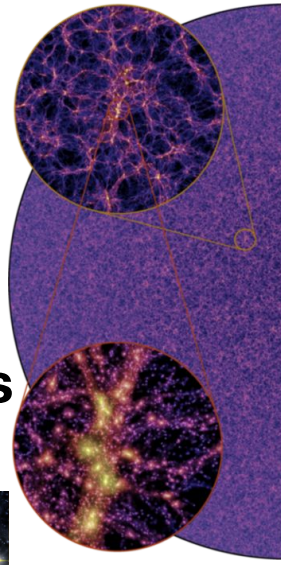
1. **Apply M_*- sSFR cut to hydro. sim. galaxies** (sSFR = SFR/M_*)

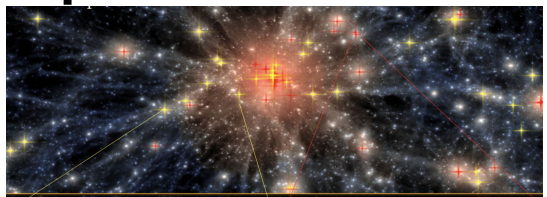
   LBGs on SF MS -> restrict 10^{-10} < sSFR <10^{-8}

2. **Match number density using minimum M_***

2 simulations:

- **MillenniumTNG (MTNG) -> 500 Mpc/h, 2×4230^3 particles**
- **Astrid -> Astrid - 250 Mpc/h, 2×5500^3 particles**



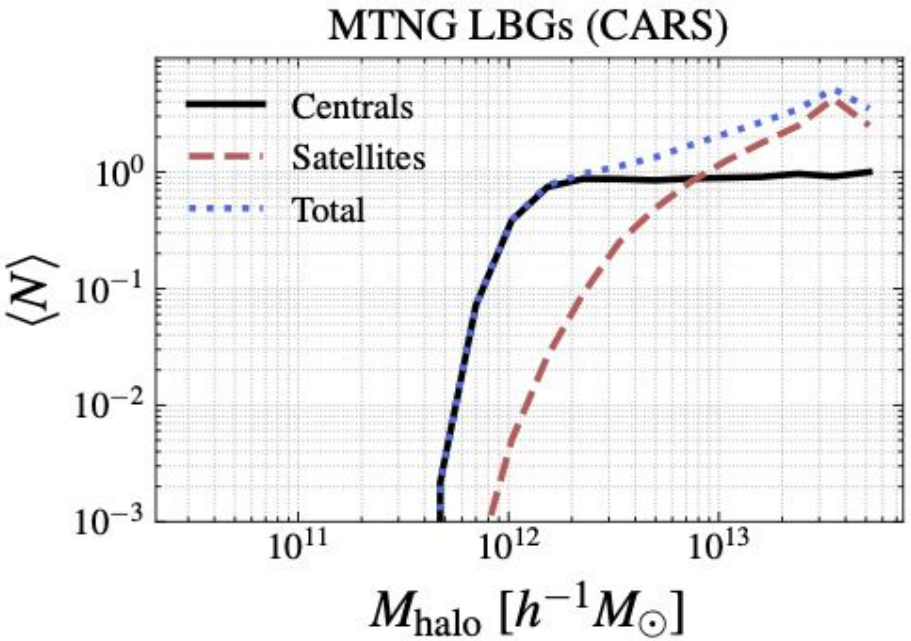


MTNG Team, Astrid Team, Pakmor+24, Bird+21

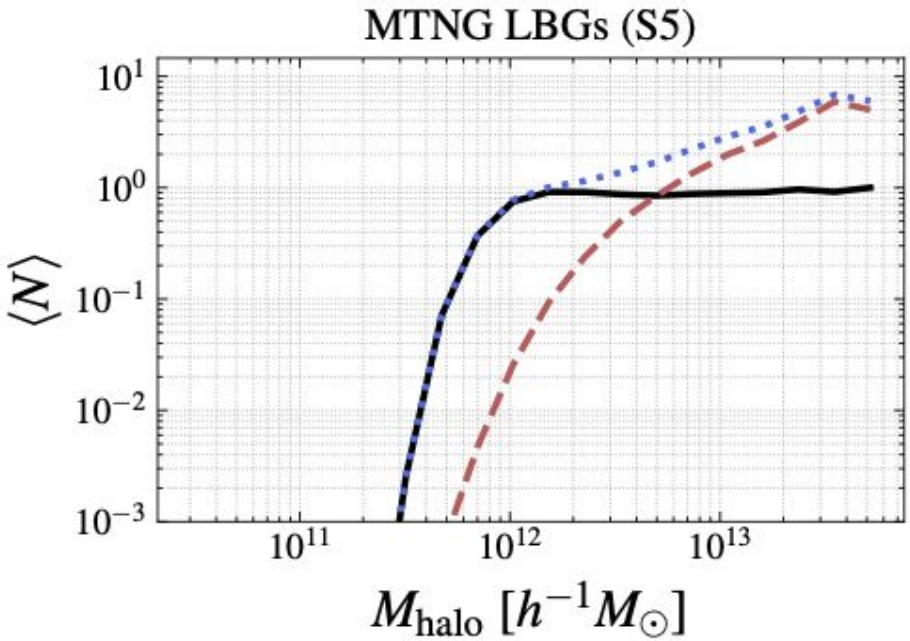
LBG HODs - MTNG

Roughly Zheng07-like

Higher min. M□



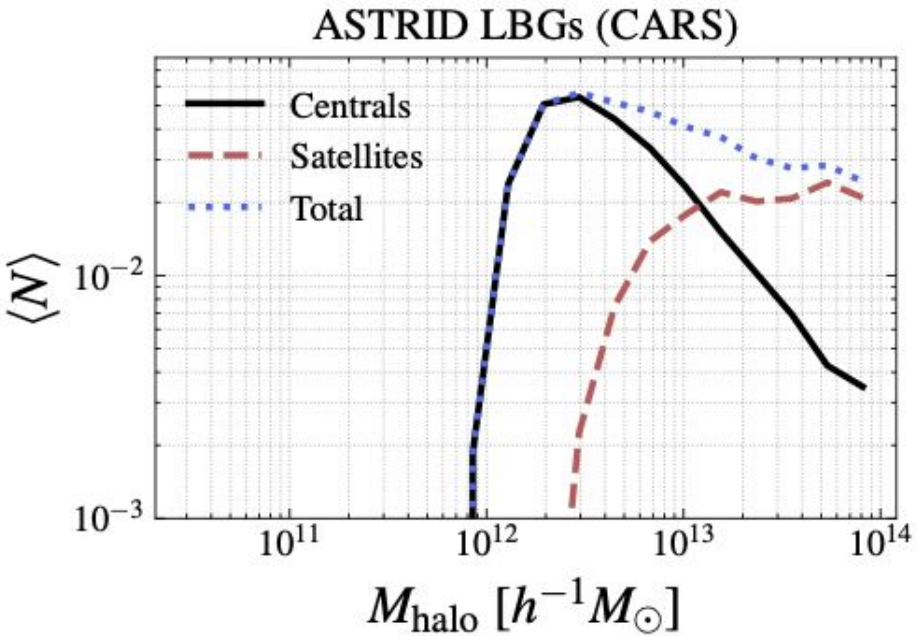
Lower min. M□



LBG HODs - Astrid

A bit different...

Higher min. M□



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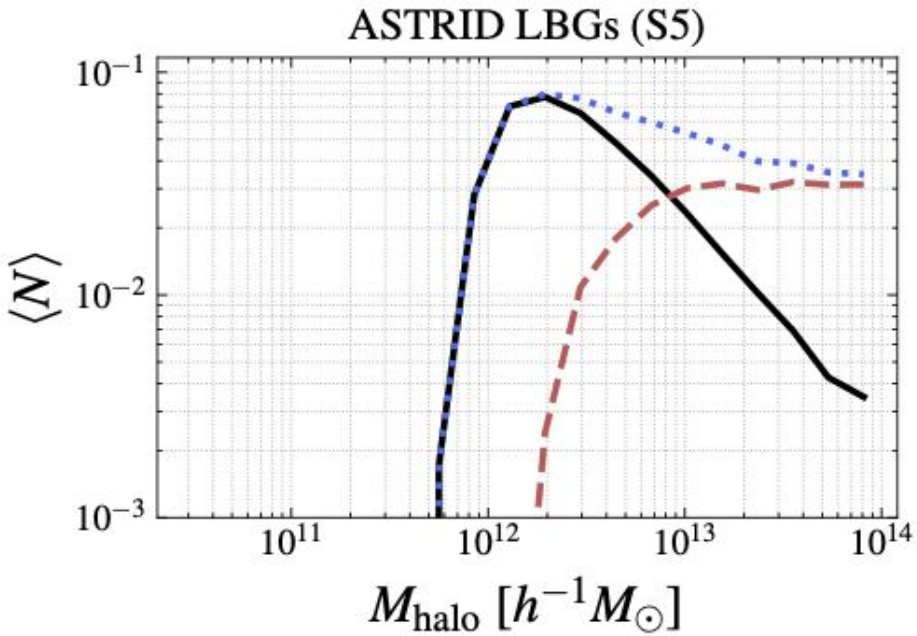


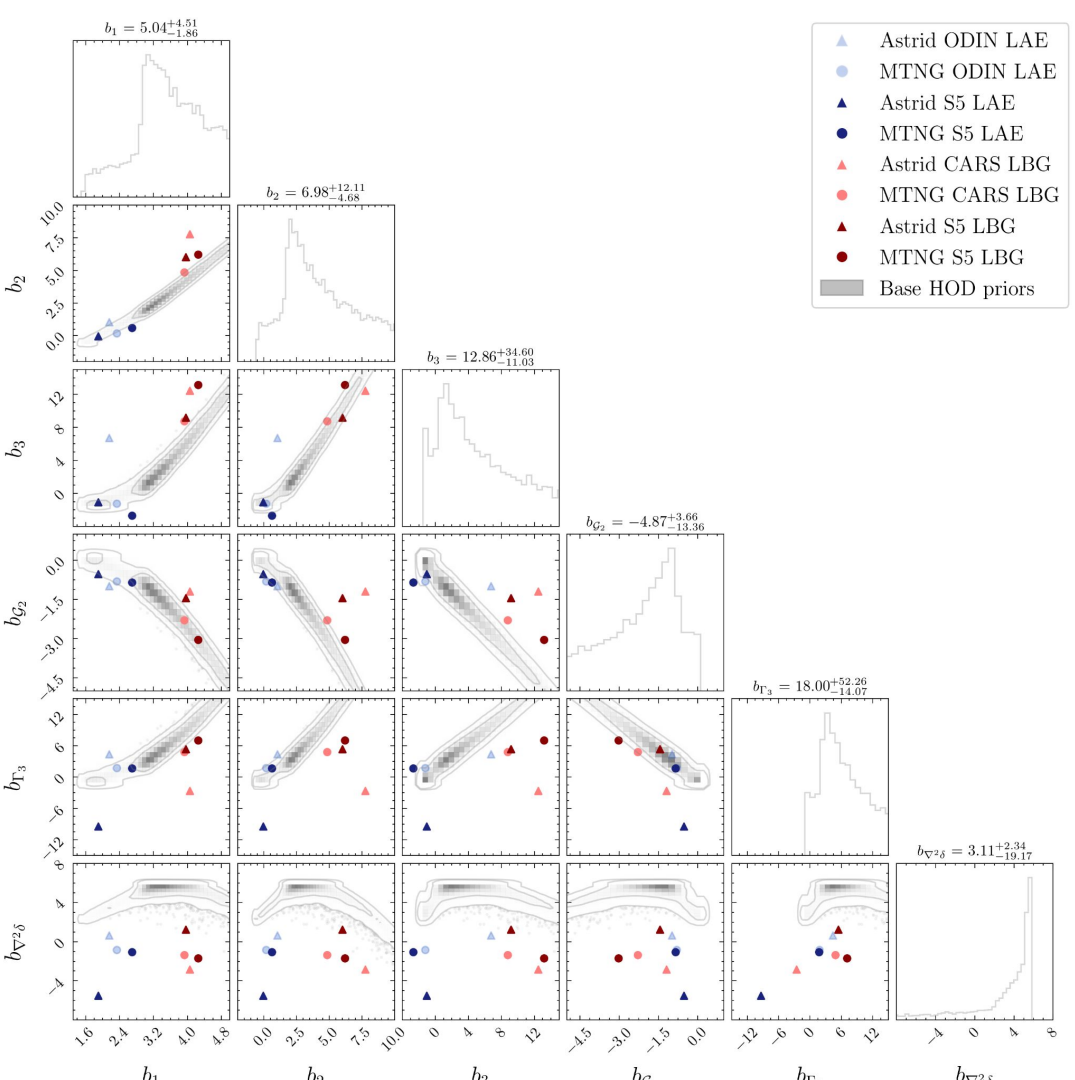
Selection Table - MTNG

		$\bar{n}\ [h^{-1}\mathrm{Mpc}]^{-3}$	$\log_{10}\left(\frac{\langle M_h \rangle}{h^{-1}M_\odot}\right)$	$b_1^{w(\theta)}$	f_{sat}	$\left\langle \frac{\sigma}{\mathrm{km/s}} \right\rangle$
LAE	ODIN	1.2×10^{-3}	11.40	2.1	30%	60
	S5	1.3×10^{-3}	11.51	2.4	15%	88
LBG	CARS	6.7×10^{-4}	12.37	3.9	12%	200
	S5	1.3×10^{-3}	12.26	3.6	10%	179

Selection Table - Astrid

		$\bar{n}\ [h^{-1}\mathrm{Mpc}]^{-3}$	$\log_{10}\left(\frac{\langle M_h \rangle}{h^{-1}M_\odot}\right)$	$b_1^{w(\theta)}$	f_{sat}
LAE	ODIN	1.3×10^{-3}	11.98	2.0	40%
	S5	1.3×10^{-3}	11.96	2.1	33%
LBG	CARS	6.7×10^{-4}	12.63	3.8	12%
	S5	1.3×10^{-3}	12.52	3.8	13%

Nonlinear bias



Zheng07-like model & priors

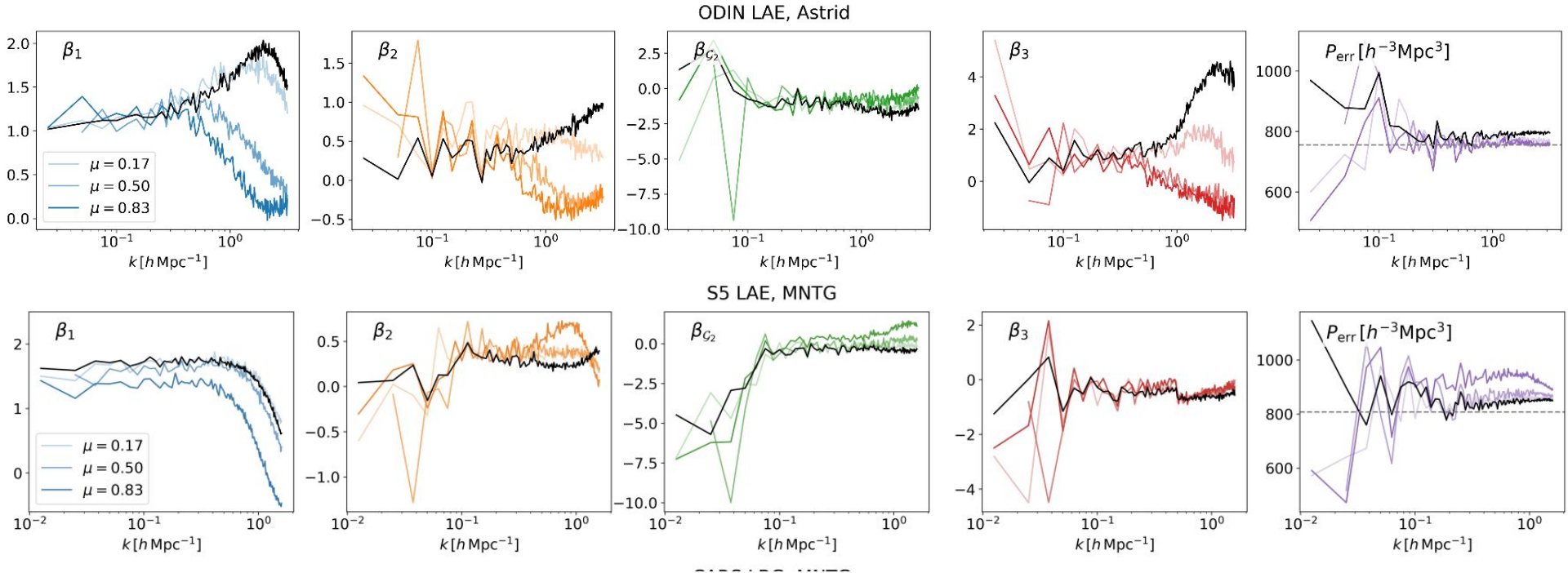
$$\log_{10} M_{\rm cut} \in [11, 13]\,, \quad \log_{10} M_1 \in [12, 14]\,,$$
$$\log \sigma \in [-3, 0]\,, \quad \alpha \in [0.5, 1.5]\,,$$
$$\alpha_c \in [0, 0.5]\,, \quad \alpha_s \in [0.7, 1.3]\,, \quad \kappa \in [0.0, 1.5]$$

$$\langle N_c \rangle (M) = \frac{1}{2}\left[1 + \mathrm{Erf}\left(\frac{\log M - \log M_{\rm cut}}{\sqrt{2}\sigma}\right)\right],$$
$$\langle N_s \rangle (M) = \langle N_c \rangle (M) \left(\frac{M - \kappa M_{\rm cut}}{M_1}\right)^{\alpha},$$

Nonlinear bias

Param.	ODIN LAE MTNG	S5 LAE MTNG	S5 LBG MTNG	CARS LBG MTNG	ODIN LAE Astrid	S5 LAE Astrid	S5 LBG Astrid	CARS LBG Astrid
b_1	2.33	2.68	3.92	4.24	2.15	1.89	4.05	3.96
b_2	0.17	0.61	4.85	6.21	1.05	-0.052	7.76	6.02
b_3	-1.23	-2.68	8.75	13.14	6.73	-1.05	12.46	9.17
$b_{\mathcal{G}_2}$	-0.803	-0.84	-2.28	-3.03	-0.98	-0.52	-1.19	-1.44
b_{Γ_3}	1.76	1.71	4.83	7.04	4.37	-9.44	-2.62	5.38
$b_{\nabla^2\delta}$	-0.84	-1.05	-1.35	-1.69	0.66	-5.49	-2.83	1.25
α_0	0.046	0.041	-0.17	-0.16	0.074	0.023	-0.307	-0.32
α_1	-0.023	-0.018	-0.0085	-0.037	-0.068	0.063	0.010	-0.047
α_2	0.18	0.32	0.73	0.48	-0.12	-0.093	0.0081	0.044
c_{μ^2}	-13.49	-24.39	-16.33	-9.22	-3.16	1.53	1.96	-1.80
b_4	-815.02	-1202.88	-692.46	-499.51	-6.09	-10.44	-43.52	-18.15

Transfers for LAEs



Thanks!